

Comment on the paper "Search for oscillation of the electron-capture decay probability of ^{142}Pm " at *arXiv:0807.0649v1*

Yu.A. Litvinov^{a*}, F. Bosch^a, N. Winckler^{ab}, D. Boutin^b, H.G. Essel^a, T. Faestermann^c, H. Geissel^{ab}, S. Hess^a, P. Kienle^{cd}, R. Knöbel^{ab}, C. Kozhuharov^a, J. Kurcewicz^a, L. Maier^c, K. Beckert^a, C. Brandau^a, L. Chen^b, C. Dimopoulou^a, B. Fabian^b, A. Fragner^d, E. Haettner^b, M. Hausmann^e, S.A. Litvinov^{ab}, M. Mazzocco^{af}, F. Montes^e, A. Musumarra^{gh}, C. Nociforo^a, F. Nolden^a, W.R. Plaß^{ab}, A. Prochazka^a, R. Reda^d, R. Reuschl^a, C. Scheidenberger^{ab}, M. Steck^a, T. Stöhlker^{ai}, S. Torilov^j, M. Trassinelli^{ak}, B. Sun^{al}, H. Weick^a, M. Winkler^a

^aGesellschaft für Schwerionenforschung GSI, 64291 Darmstadt, Germany

^bJustus-Liebig Universität, 35392 Gießen, Germany

^cTechnische Universität München, 85748 Garching, Germany

^dStefan Meyer Institut für subatomare Physik, 1090 Vienna, Austria

^eMichigan State University, East Lansing, Mi 48824, U.S.A.

^fDipartimento di Fisica, INFN, I35131, Padova, Italy

^gINFN-Laboratori Nazionali del Sud, I95123 Catania, Italy

^hUniversità di Catania, I95123 Catania, Italy

ⁱRuprecht-Karls Universität Heidelberg, 69120 Heidelberg, Germany

^jSt. Petersburg State University, 198504 St. Petersburg, Russia

^kINP, CNRS UMR 7588, France and Université Pierre et Marie Curie-Paris6, Paris, France

^lPeking University, Beijing 100871, China

It is argued that orbital electron-capture decays of neutral ^{142}Pm atoms implanted into the lattice of a solid (LBNL experiment) do not fulfil the constraints of *true two-body beta decays*, since momentum as well as energy of the final state are distributed among three objects, namely the electron neutrino, the recoiling daughter atom and *the lattice phonons*. To our understanding, this could be a reason for the non-observation of a periodic time modulation in the number of electron-capture decays of implanted neutral ^{142}Pm atoms.

The authors report on a measurement [1] at the 88 inch LBNL cyclotron of the orbital electron-capture (EC) decay probability of ^{142}Pm atoms implanted into a metallic matrix (most probably in the neutral charge state immediately after implantation). They found a pure exponential decrease of the number of EC decays per time unit,

without a significant periodic modulation of the decay curve. This is seemingly in disagreement to our findings at GSI [2] for the EC decay of stored and cooled hydrogen-like $^{142}\text{Pm}^{58+}$ ions, where a time modulation with a period of 7 seconds and a (normalized) amplitude of about 0.2 was observed. In searching for possible reasons of the diverging results, the authors discuss for instance,

*E-mail: y.litvinov@gsi.de

whether the remaining electrons—in the Berkeley case—“could provide a decoherence of the neutrino momentum states in the larger phase space of the final atomic states after the decay”. It is argued that this is most probably not the case, since “our experiment detected K-shell x-rays, meaning that the captured electron was indeed a K-shell electron with a similar wavefunction to the hydrogenic ions investigated” [at GSI].

We have no objections against this reasoning. Moreover, we appreciate the very carefully planned and conducted experiment at Berkeley as well as its detailed description and interpretation. However, we want to emphasize what is in our opinion the fundamental difference of an experiment observing EC decays of implanted neutral atoms on the one hand, and an experiment recording EC decays of ‘free’ hydrogen-like ions (albeit confined by magnetic fields) on the other hand. In the former case we have not a true two-body decay, since in the final state momentum as well as energy are distributed among three objects, the electron neutrino, the recoiling daughter atom (recoil energy of about 90 eV for the daughter atom ^{142}Nd) and the lattice phonons. The recoil energy of the daughter atom has a distribution, which is only on an average equal to the recoil energy of the free case. This means that also the neutrinos have the corresponding energy distribution and are therefore not mono-energetic as in the ‘free’ decay.

We addressed this point already in the last sentence of our paper [2]: “Finally, an interesting case arises when the decaying nucleus is not free but couples to the full phonon spectrum in the lattice of a solid”. Indeed, only for a true two-body EC-decay as, for instance, from the ground state of a stored hydrogenic parent ion to the ground state of its bare daughter ion without involving a third object, a strict entanglement exists concerning momentum and energy of the neutrino mass eigenstates on the one hand, and of the corresponding recoiling nuclei on the other hand. We discussed this point on p. 167, third paragraph, of [2].

Neither at Berkeley nor at GSI the generated neutrinos are directly observed. In both experiments the time of the decay with respect to the

generation of the parent atom is precisely determined, via the appearance of a characteristic K x-ray (Berkeley), or via a sudden change of the mass of the stored ion (GSI). We argue that only the latter case represents a true two-body beta decay. Indeed, we get from the precisely determined change of the mass the direct, time-resolved and complete information at the hadronic vertex, i.e. on the transformation of a proton to a neutron, as well as at the leptonic vertex, i.e. on the annihilation of the K-shell electron and, thus, on the generation of a neutrino in the electron-flavour eigenstate (supposing lepton number conservation in the weak decay). This knowledge could be the necessary condition for observing any kind of interference in those decays.

It is interesting to note that the observed modulation frequency, if indeed due to the interference of two neutrino mass eigenstates, corresponds to a very small neutrino and, thus, daughter recoil energy difference of about $8 \cdot 10^{-16}$ eV. This is much smaller than typical phonon energies excited by the recoiling daughter nuclei in an aluminum lattice which are in the order of meV. Thus, the modulations could be washed out in a solid environment. The very small energy difference measured in the GSI experiment is in the order of that expected for the squared neutrino mass difference of 10^{-4} eV² as pointed out in our paper [2].

Concerning almost all other questions mentioned, we fully agree with the authors: A measurement of the EC-decay of helium-like ^{142}Pm ions should reveal the (probably small) differences to the EC-decay of hydrogen-like ions (such time-resolved measurements are planned, but not yet performed). And, without doubt, the outcome of the three-body β^+ decay of ^{142}Pm is crucial for the interpretation of the GSI data. The—not simple—evaluation of this data is still in progress.

REFERENCES

1. P.A. Vetter *et al.*, arXiv:0807.0649v1 [nucl-ex]
2. Yu.A. Litvinov *et al.*, Phys. Lett. B**664** (2008) 162.